Fermilab

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Prof. Atul Gurtu
Tata Institute of Fundamental Research
Mumbai, India

Dear Prof. Gurtu,

Fermilab will like to submit the attached document for consideration by your committee on Future prospects of High Energy Physics in India.

US and Indian Laboratories and Universities, especially Brookhaven National Laboratory and Fermi National Accelerator Laboratory in the United States and Tata Institute for Fundamental Research in India, have a long tradition of collaboration in elementary particle physics.

There are two specific areas in which collaboration between Fermilab and Indian institutions is likely to benefit, International Linear Collider and Neutrino Physics. Fermilab would like to propose direct collaboration on the following projects.

1. MINOS experiment at Fermilab
2. NOνA Proposal at Fermilab
3. Proton Driver Accelerator R&D
4. International Linear Collider Accelerator R&D
5. International Linear Collider Detector R&D

One of the key objectives of this proposal is to find physics and R&D topics of common interest to both US and Indian institutions that will help advance our common R&D interests. The collaboration will provide a platform for training of young Indian students and scientists, who will be exposed to the cutting edge technology. This will also enable India to collaborate and develop accelerator and detector technology needed for Indian programs. Indian scientists can contribute and significantly benefit from these projects.

If you need additional information please let me know. Thank you.

Sincerely,

Smishra

Shekhar Mishra

Cc:

Piermaria Oddone

Steve Holmes

Huge Montgomery

Robert Kephart

Stanley Wojcicki

Gary Feldman

Vinod Sahni

International Linear Collider

The International Linear Collider (ILC) is a proposed future international particle accelerator with the highest priority recommendation by the International Committee on Future Accelerator (ICFA). The ILC would create high-energy particle collisions between electrons and positrons. The ILC would provide a tool for scientists to address many of the most compelling questions of the 21st century-questions about dark matter, dark energy, extra dimensions and the fundamental nature of matter, energy, space and time. Fermilab is the proposed host of ILC in USA.

The ILC Main Linac will use the Superconducting Radio Frequency technology. The superconducting technology has wide range of applications in accelerator developments including Proton Driver, accelerators for applied research, biology and medicine. This technology is also being used in construction of X-ray Free Electron Laser for applied research in semi-conductor and biology. The main focus of the Fermilab ILC R&D is to lead and establish technical capabilities in the Superconducting Radio Frequency Cavity and Cryomodule technology. The main focus of the R&D efforts will be towards developing the SRF cavity technology to achieve 35 MV/m with a Q of $\sim 0.5 \times 10^{10}$, ILC cryomodule design, and fully test the basic building blocks of the ILC Main Linac with beam. The strategic approach we are taking is to involve industry in the cavity fabrication and to use the existing infrastructure at the collaborating institutes to reliably establish ILC level gradients and Q. Fermilab's ultimate goal is to develop a cryomodule design and assembly process suitable for ILC. India could play a significant role in cost reduction and construction of ILC accelerator components.

Fermilab is interested in exploring collaborative opportunities with Indian laboratories, engineering institutes and industries on ILC Main Linac Accelerator R&D. We could also discuss collaboration on Civil Engineering and High Power Radio Frequency development for ILC. University of Delhi is collaborating on Main Linac accelerator physics. Other institutions with simulations and design interest can collaborate on Accelerator design.

Fermilab is jointly leading the SiD detector design R&D for the ILC. We would like to explore the possibilities of collaboration on ILC detector R&D specially in the areas of in Pixel, Silicon microstrip, calorimeter and Muon detectors.

Further information can be found at http://ilc.fnal.gov/.

MINOS EXPERIMENT

The MINOS Experiment is a long baseline neutrino oscillation study, utilizing the neutrino beam produced by the 120 GeV Fermilab Main Injector accelerator and two detectors: the near one at Fermilab 1km away from the target and a far one located underground in a former iron mine in Minnesota, about 735 km away. The energy spectrum of the neutrinos can be adjusted by varying the position of the target and/or second horn with respect to the first horn and can span a range from 2 to 15 GeV. The power of the beam is currently ~0.2 MW and will rise to ~0.4 MW.

The far detector is a 5.4 Kton sampling calorimeter composed of 485 8m wide octagonal layers of iron, 2.54 cm thick and solid scintillator 1.0 cm thick. The scintillator planes are composed of 4.1 wide strips with imbedded wavelength shifting fibers read out on both ends via Hamamatsu 16 pixel PMT's. The near detector has a mass of about 1 Kton and a similar basic structure as the far detector. Both detectors are energized by a current carrying coil producing an average field of about 1.3 T.

The far detector was completed in the summer of 2003 and taking data on cosmic rays and atmospheric neutrinos since that time. The first paper on atmospheric neutrinos is being submitted for to Physical Review. This will be the first measurement distinguishing neutrinos and antineutrinos, made possible by the presence of the magnetic field.

The near detector and the beam were completed at the end of 2004 and the first neutrino interactions were observed at the beginning of 2005. Data are currently being taken in the low energy beam configuration (mean neutrino energy about 3 GeV). It is expected that 10^{20} protons on target will have been delivered by the end of this year which should give several hundred neutrino interactions in the far detector allowing a measurement of Δm^2_{23} with a higher precision than the best currently available.

The main goals of the MINOS Experiment are:

a) precise measurements of the oscillation parameters in the atmospheric region, specifically Δm^2_{23} with an accuracy of 10% or so.
b) Unequivocal demonstration that the oscillation mechanism is responsible for the observed ν_μ disappearance.
c) Measurement (or improvement of limits) of θ_{13} parameter. An impovement by a factor of 3 over the current limit appears possible over a 4 year run
d) Further study of oscillation parameters separately for atmospheric neutrinos and antineutrinos

The MINOS Collaboration is happy to explore the possibility of new groups joining the collaboration. The main construction of the experiment is now behind us but there are numerous tasks where new groups could contribute to running and improving the experiment (besides work on physics analysis): work on improving beam intensity, upgrading beam, improvements in software, data taking shifts, participation in maintenance of current hardware. Since the "counting room" for the experiment is remote for either Near or Far detectors the experiment already operates "remote shifts".

THE NOνA EXPERIMENT

The NOνA experiment, designed to be the second experiment on the NuMI beam line, will search for and study $\nu_\mu \rightarrow \nu_e$ oscillations with approximately an order of magnitude more sensitivity than the MINOS experiment.

Like the MINOS experiment, NOνA will be a two-detector experiment, with the near detector on the Fermilab site approximately 1 km from the NuMI target and the far detector near Ash River, Minnesota, 810 km from Fermilab. The far site was chosen because it is the furthest practical site from Fermilab along the NuMI beamline in the United States. The longest possible baseline maximizes the matter effect, *i.e.*, the coherent interaction of ν_e with the electrons in the earth, which is the only means of determining the ordering of the neutrino masses.

Unlike the MINOS experiment, which is centered on the NuMI beam line, the NOνA experiment will be located 15 mrad or 12 km off the axis of the beam line. The advantage of this off-axis location is that the relativistic kinematics of pion decay produces a narrow-band neutrino beam with more flux close to the oscillation maximum and with less background than an on-axis beam.

The NOνA far detector will be a 30 Kton "totally active" detector, consisting solely of liquid scintillator contained in 32-cell PVC extrusions with cell width and depth 3.9 cm by 6 cm, and length 15.7 m. This design gives 10 times the longitudinal segmentation of the MINOS detector, 0.15 radiation lengths for NOνA versus 1.5 radiation lengths for MINOS. The fine segmentation of NOνA gives good electron identification and electron-pion electron-muon discrimination. There will be 1984 planes, each with 12 32-cell extrusions, with planes alternating horizontal and vertical extrusions.

The liquid scintillator cells will be read out by a U-shaped wavelength-shifting fiber with both ends terminating in a pixel of a 32-pixel avalanche photodiode (APD). The high quantum efficiency of the APDs yields a sufficient number of photoelectrons to allow the use of the very long extrusions.

NOνA will run after the Tevatron collider ceases operation. This allows parts of the Fermilab accelerator complex now used for antiproton accumulation to be used for the neutrino program. The NOνA proposal was based on the assumption of 0.625 MW on target. The construction of Proton Driver at Fermilab would allow 2-4 MW. However, even if the Proton Driver is not constructed, it is possible that the present accelerator could be upgraded to provide beams of between 1 and 2 MW power.

At 0.625 MW, a six-year NOνA run split evenly between neutrino and antineutrino running would provide 3-σ sensitivity to $\theta_{13} \neq 0$ for θ_{13} in the range 0.008 to 0.018, depending on the mass ordering and the CP-violating phase δ. With the Proton Driver, the sensitivity would increase by approximately a factor of 2. The unique feature of the NOνA experiment is its ability to measure the mass ordering due to its long baseline. Without the proton driver, NOνA will have the ability to resolve the mass ordering for at least some values of δ for $\theta_{13} > 0.03$. For some values of δ, there will be an inherent ambiguity between the effect of the mass ordering and CP violation, which will require a third measurement for its resolution. This can be done by comparing NOνA's measurements either with those from another experiment at a different baseline or with an experiment that measures the second oscillation maximum.

NOνA will be able to make several other important measurements. For example, its totally active nature and its excellent energy resolution will allow a very precise measurement of $\sin^2(2\theta_{23})$. NOνA will also be able to measure the neutrinos from a supernova if one occurs in the galaxy during the running of the experiment.

The NOνA experiment was approved by Fermilab in April 2005 and is now proceeding to complete the requirements to receive Department of Energy funding for a construction start in October 2007. To meet this goal, our schedule calls for a Conceptual Design Report in December 2005 and a Technical Design Report in May 2006. To accomplish this, a project organization has been set up with John Cooper and Ron Ray, both of Fermilab, as Project Manager and Deputy Project Manager, respectively. Gary Feldman of Harvard University is the Spokesman of the experiment.

The NOνA experiment is open to additional collaborators. There is a great deal of work left to be done in research and development, design, and simulation. NOνA has not yet made any assignments of responsibility for the construction of the various components of the experiment. Although the project organization has a full set of Level 2 managers, there are possibilities for co-managers if new collaborators wish to take on major responsibilities. There are also several Level 3 manager positions that are still open.

More information on NOνA can be found on its web site, http://www-nova.fnal.gov/. In particular, more details of the experiment and its physics capability can be found in a recent talk posted at http://www-nova.fnal.gov/NOvA_Talks_and_Presentations/-2005_talks/Feldman_WIN05_Plenary.pdf.

PROTON DRIVER

The Proton Driver is a 8 GeV superconducting H^- linac designed to enable proton beam intensities in excess of 2 MW at energies between 8 and 120 GeV within the existing Fermilab accelerator complex. The primary goal of the Proton Driver is to retain a world-leading neutrino program at Fermilab. The unique linac design utilizes concepts and shares technology with high intensity proton and/or ion facilities within the first 1 GeV, and with the International Linear Collider above 1 GeV.

The Proton Driver will provide 1.6×10^{14} H^- ions per pulse for injection into the existing Main Injector accelerator. The Main Injector is capable of accelerating beam to 120 GeV for delivery onto a suitable target every 1.5 seconds. The total beam power is thus 2.05 MW. This beam power can be maintained at any energy down to about 30 GeV through reduction of the cycle rate at lower energies and is upgradeable to 3-4 MW by improvement to the Main Injector ramp rate. In addition linac cycles not used for injection into the Main Injector can be used to provide approximately 0.4 MW (upgradeable to 2 MW) of beam power at 8 GeV simultaneous with the Main Injector based program.

The Proton Driver utilizes superconducting rf as its base technology. The low energy end (up to about 1.2 GeV) is based on low β superconducting accelerating structures operating at 325 MHz—one quarter of the proposed ILC operating frequency and very close to the frequency used in the J-PARC project. This technology is equally adaptable for utilization for neutron source applications or for acceleration of heavy ions. However, within the Proton Driver an innovative rf distribution scheme will be employed that dramatically reduces the number of rf power sources as compared to facilities currently under construction. The high energy (1.2 – 8 GeV) portion of the linac is based on ILC accelerating structures operating at 1.3 GHz. Development of this technology for Proton Driver will proceed in parallel with ILC. Indeed, if the ILC were delayed the Proton Driver could serve as a test bed for development of industrial capabilities and for operational experience aimed at a subsequent ILC construction.

The Proton Driver is currently in the pre-conceptual design stage. A design concept exists and R&D is underway. Approval for construction is several years off, but if all goes well construction could be initiated late in the current decade.

Collaborative opportunities exist in both the design of the facility, the associated technology R&D programs, and ultimately in construction. Topics requiring attention run the full gamut of ion sources, low β superconducting structures, rf sources and amplitude/phase controllers, conventional magnets, instrumentation, power supplies, and development/industrialization of high performance relativistic accelerating structures. (Thirty six 8-cavity cryomodules are required for the full facility). Further information can be found at http://protondriver.fnal.gov/.

The acceleration of electron is also possible with the Proton Driver Linac by addition of an electron front end. This could enable one accelerator complex to provide high power proton and electron beams for different users including neutrino physics, condensed matter and applied research in biology etc.